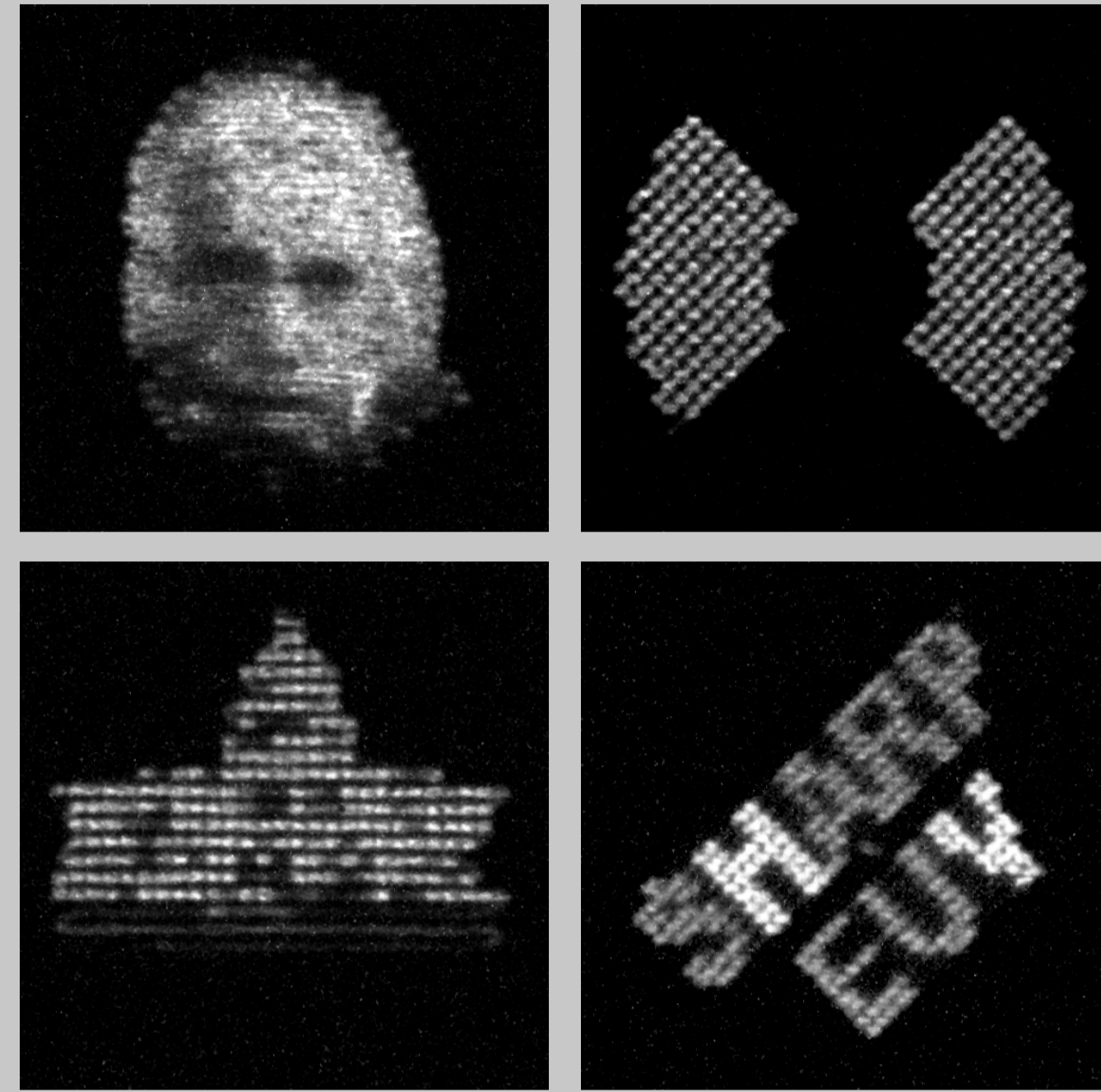# Source optimization at the SHARP microscope

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Summary

Source optimization and source-mask optimization (SMO) are techniques to optimize the angular composition of the source or the properties of source and mask together, in order to achieve the largest process window for a given pattern. These techniques are implemented in DUV lithography to extend a given Numerical Aperture (NA) down to smaller k factors and smaller nodes consequentially. We expect SMO to be applied by future EUV lithography generations.
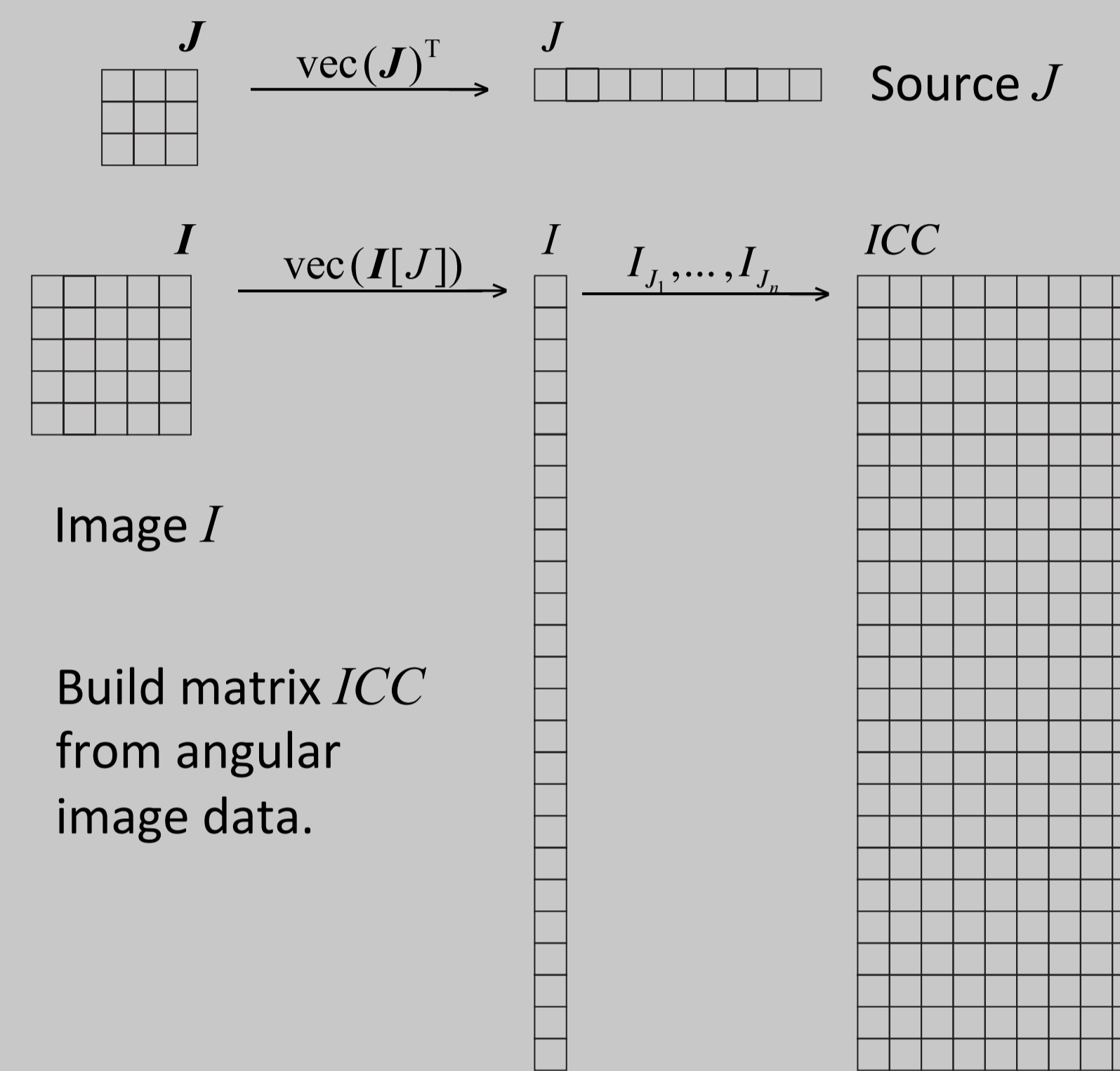
The SEMATECH High-NA Actinic Reticle review Project, SHARP, is a synchrotron-based microscope dedicated to advanced EUV mask imaging [1]. Its unique, lossless Fourier Synthesis Illuminator with fully programmable angular source distributions makes SHARP the ideal tool to study EUV imaging under varying source parameters. A set of image data was recorded using monopole illumination from 284 different angles, covering the pupil. This data is used for numeric source optimization. Successful reconstruction of pupil fills from image data shows the validity of the approach.

Fourier Synthesis Illuminator[2]

MEMS chip with M_A mirror, 1-mm diameter.

M_A: MEMS-driven flat multilayer mirror, scanning the pupil
M_B: Flat folding mirror
M_C: Ellipsoidal condenser mirror with 10x demagnification

Pupil fills

Intentionally pixelated pupil fills on SHARP recorded with a YAG-scintillator camera. These examples of continuous and pixelated angular source spectra demonstrate both binary and continuous modulation of flux.

0.2 σ

Data*

Set of images, recorded with monopole illumination from 284 angles on a 20x20 grid, covering the whole pupil

Source optimization method[3]

J $\xrightarrow{\text{vec}(J)^T}$ J Source J

I $\xrightarrow{\text{vec}(I[J])}$ I $I_{J_1}, \ldots, I_{J_n}$ ICC

Image I

Build matrix ICC from angular image data.

Solve
$$I = ICC \cdot J$$

for target Image I, using Gradient Descent:

$J = J_0$

$\text{while} \quad F > F_{\min} \quad \{$

$F = \left| S(ICC \cdot J) - S(I) \right|^2$

$\nabla F = -2a ICC^T \left[\left(S(I) S(ICC \cdot J) \right) \left(1 - S(ICC \cdot J) \right) \cdot S(ICC \cdot J) \right]$

$J = J + \gamma \nabla F \qquad \}$

with

Sigmoid function $S(I) = \dfrac{1}{1 + e^{-a(I-b)}}$
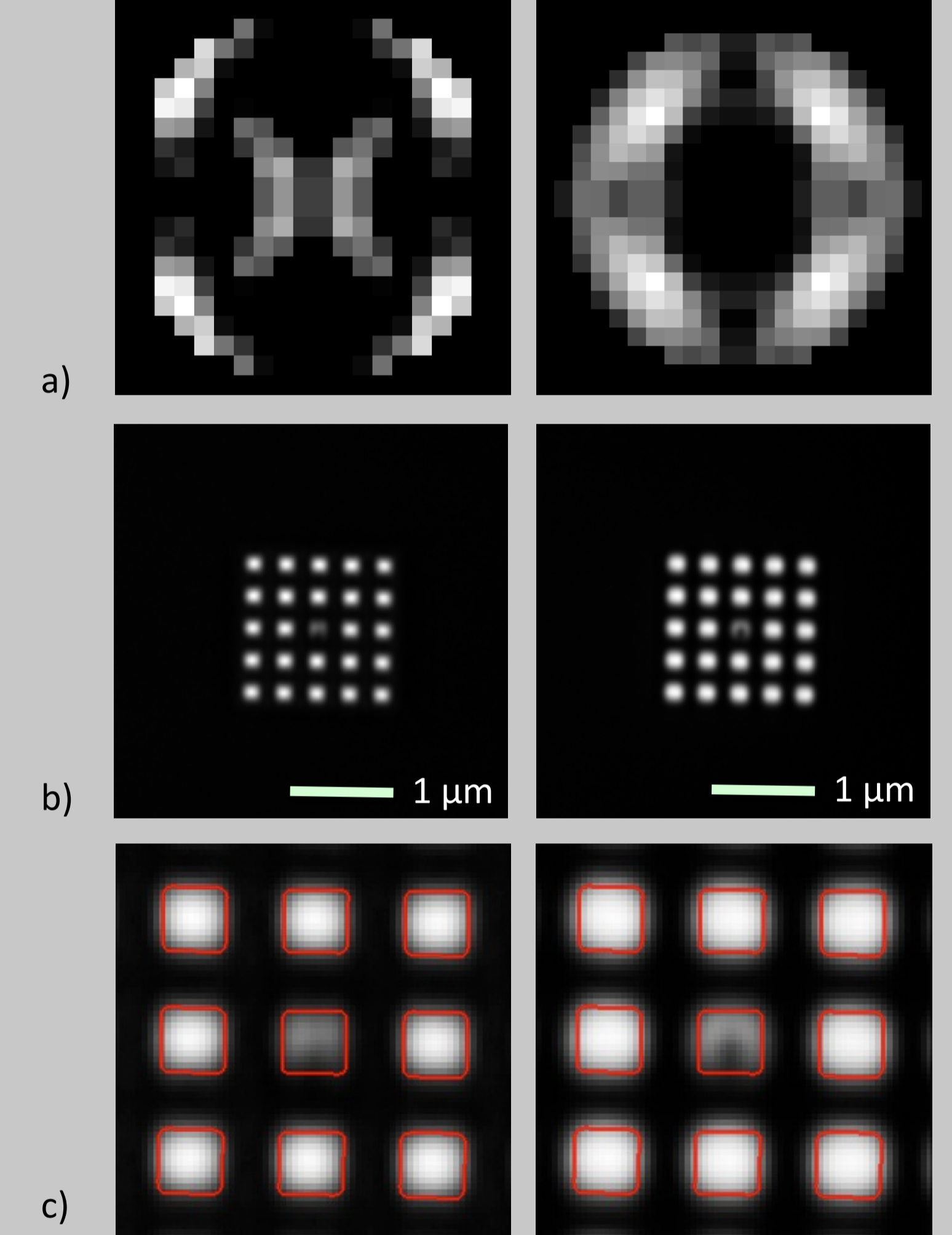
Reconstruction of pupil fills

a)

b)

c)

d)
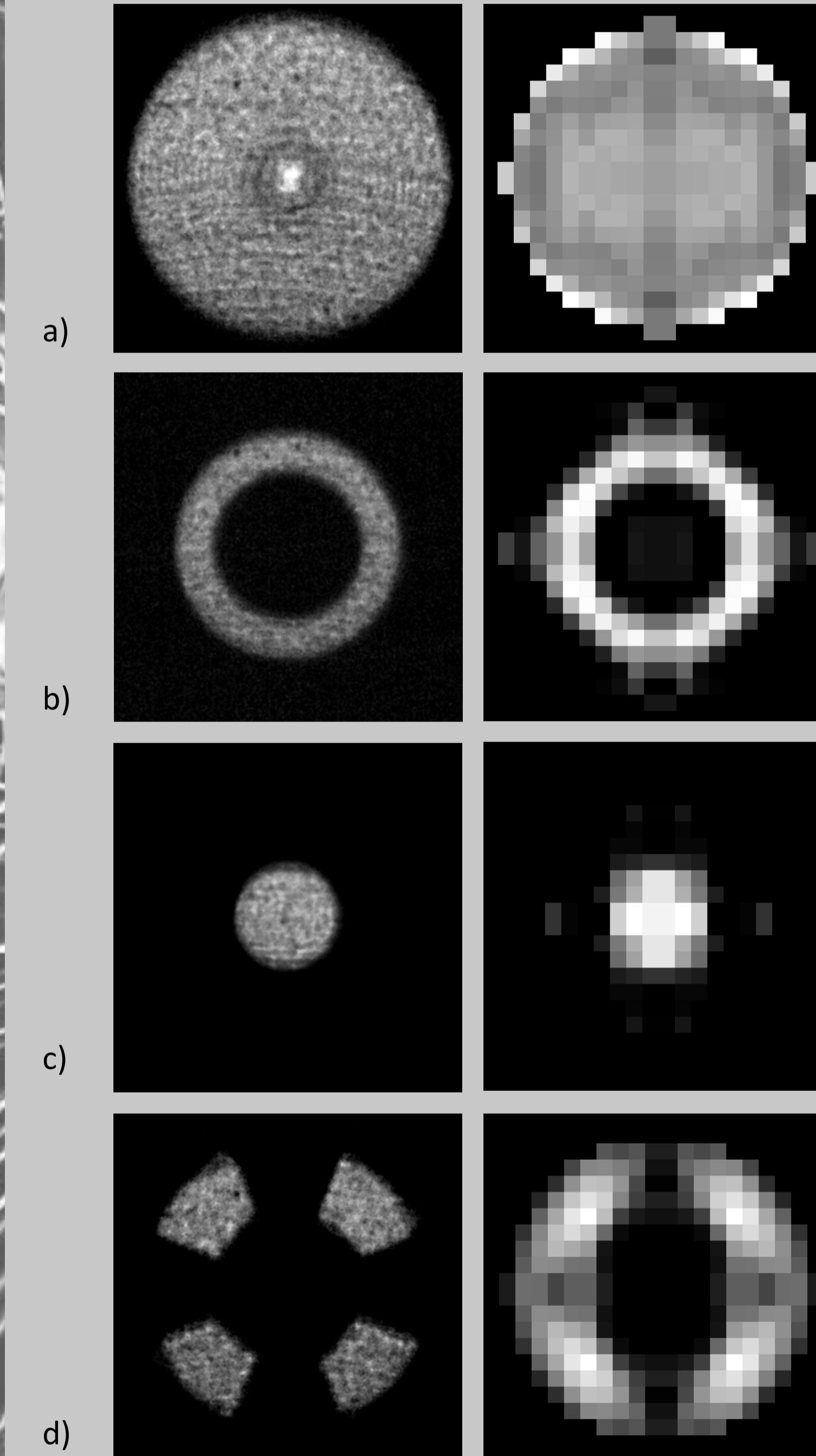
Left: YAG-scintillator camera image of pupil fill used during exposure.
Right: Reconstruction of the pupil fill from corresponding image data.

a) disk, σ=1;   b) annular, σ=0.5 to 0.7;   c) disk σ=0.3
d) crosspole 45°, σ=0.5 to 0.9, 45° arc angle

Result

a)

b)

1 µm   1 µm

c)
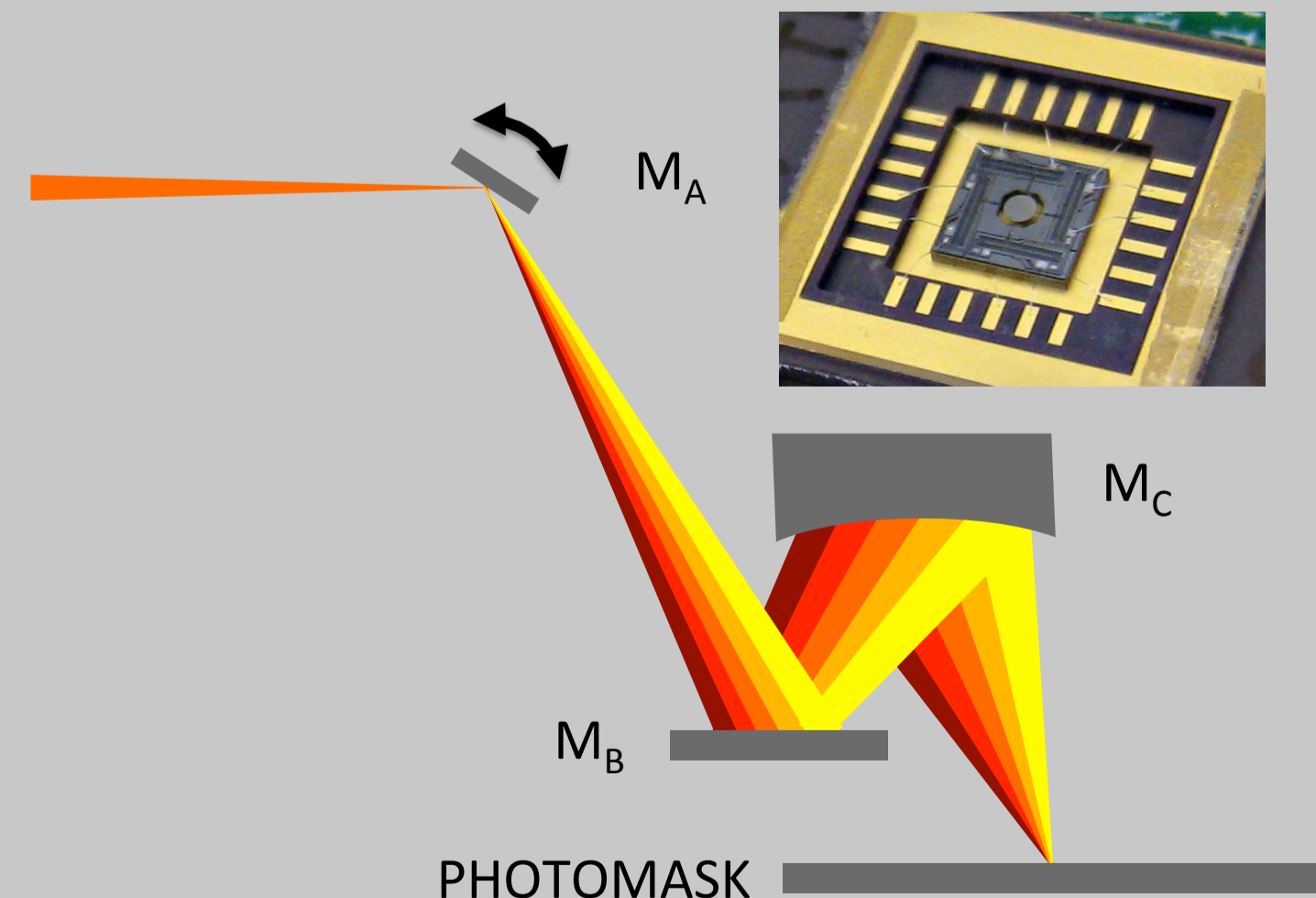
Left: a) Optimized pupil fill for 160-nm 1:1 contacts
     b) Corresponding aerial image.
     c) Magnified detail from b, showing target outline of of contacts at 50% intensity level in red.
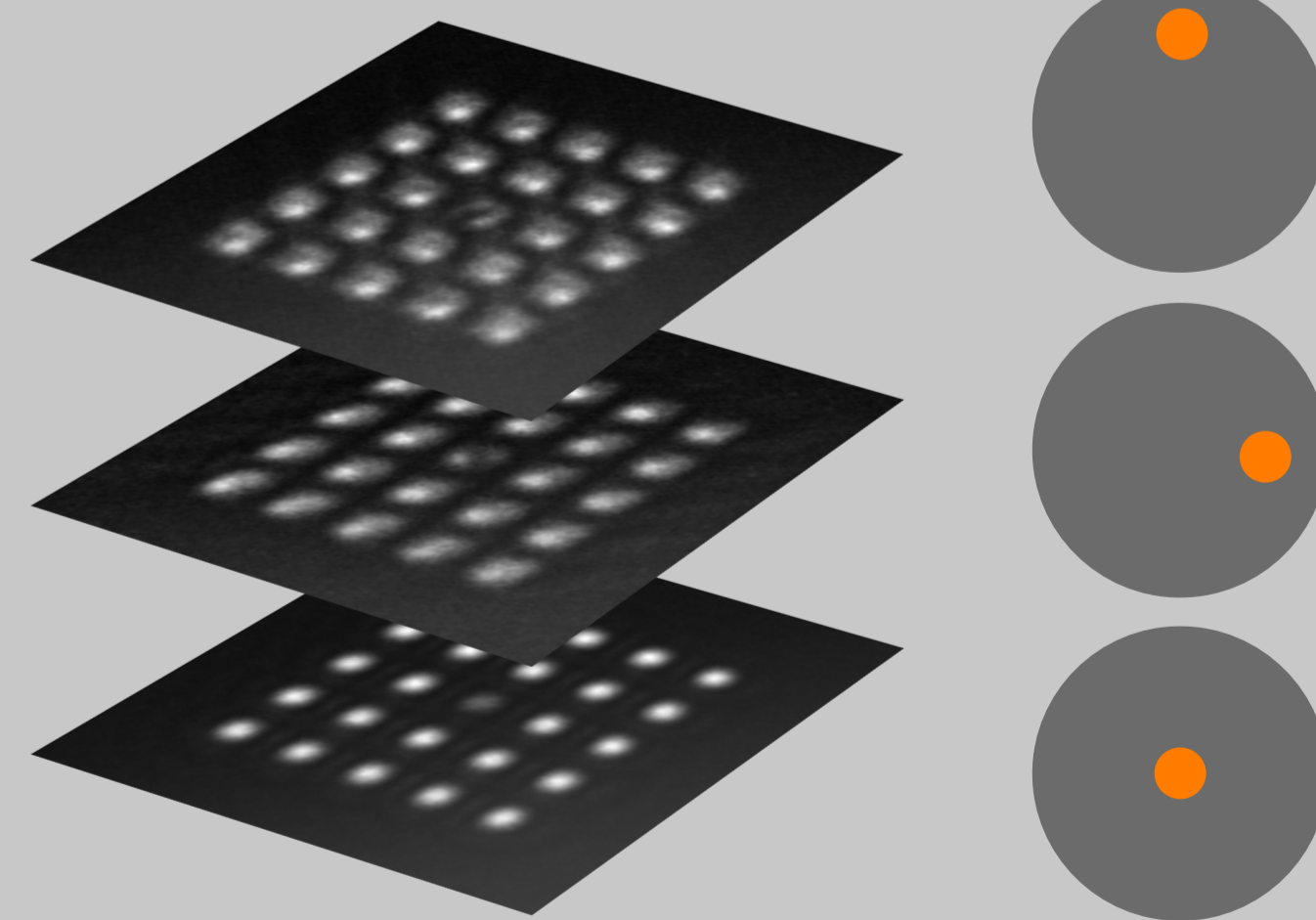Right: Data obtained from the crosspole in comparison.

References

1) Goldberg, K. A. et al., Proc. of SPIE Vol. 8679, 867919 (2013).
2) Naulleau, P. P. et al., APPLIED OPTICS 42(5), 820-826 (2003).
3) Yu, J. C., et al., OPTICS EXPRESS 20(7), 8161-8176 (2012).

*The photomask used in this study was provided by IBM.